The Bendability of Ultra High strength Steels

Hazra, S. K. , Efthymiadis, P. , Alamoudi, A. , Kumar, R. L. V. , Shollock, B. and Dashwood, R.

Original citation:
Hazra, S. K. , Efthymiadis, P. , Alamoudi, A. , Kumar, R. L. V. , Shollock, B. and Dashwood, R. (2016) The Bendability of Ultra High strength Steels. Journal of Physics: Conference Series, volume 734 : 032097

URL: http://dx.doi.org/10.1088/1742-6596/734/3/032097
DOI: 10.1088/1742-6596/734/3/032097

Publisher: IOP Publishing

The Bendability of Ultra High strength Steels

S K Hazra[1], P Efthymiadis[1], A Alamoudi[2], R L V Kumar[1], B Shollock[1] and R Dashwood[3]
[1]WMG, University of Warwick, Coventry CV4 7AL, UK
[2]School of Engineering, University of Warwick, Coventry CV4 7AL
[3]Coventry University, Priory Street, Coventry CV1 5FB

Abstract. Automotive manufacturers have been reducing the weight of their vehicles to meet increasingly stringent environmental legislation that reflects public demand. A strategy is to use higher strength materials for parts with reduced cross-sections. However, such materials are less formable than traditional grades. The frequent result is increased processing and piece costs. 3D roll forming is a novel and flexible process: it is estimated that a quarter of the structure of a vehicle can be made with a single set of tooling. Unlike stamping, this process requires material with low work hardening rates. In this paper, we present results of ultra high strength steels that have low elongation in a tension but display high formability in bending through the suppression of the necking response.

1. Introduction

The UK manufactures over 1.6 m vehicles per annum, which is predicted to rise 9% annually. The sector accounts for 7.3% of manufacturing output and 5.2% of manufacturing employment [1]. Automotive manufacturers, however, are facing increasing demands to minimise the environmental impact of their products through lightweighting while improving safety standards. For example, the UK government passed the Climate Change Act (2008) to reduce its emissions by 80% from 1990 levels by 2050. The contradictory environmental and safety demands have led to increasing use of high strength materials such as ultra-high strength steel (UHSS) that have a high strength to weight ratio. These materials have ultimate tensile strengths above 1000MPa but low elongations, making them difficult to form with the conventional cold stamping process.

One way to adopt low formability materials is to use alternative processing routes such as roll-forming[2]. Roll forming increases formability by deforming material through incremental, localised bending [3]. Sheet material flows through a series of rollers rigidly mounted on stands that bend the sheet as it flows through the rollers. The number of stands depends on the complexity of the geometry and can range from 4 to 35. Roll forming is cheap to operate, involves high material utilisation and is environmentally friendly but is limited to processing parts with a single cross-section along its length. Even though the geometry of this cross-section can be more complex than what can be achieved by stamping, forming a fixed cross-section along the length of a part limits its appeal for processing automotive parts, which frequently requires a varying cross-section along its length.

The limitation of the method is being addressed by the recent development of the flexible roll forming process [4]. With this method, the individual rolls are mounted on actuators that can change the

position and orientation of the rollers as a sheet flows through. With correct control, parts with continually varying cross-sections along its length can be produced. Flexible roll forming, therefore, opens up the possibility of roll forming automotive components with high strength materials such as UHSS.
Recent work on roll forming has looked into the effect of residual stresses on the springback on the final part. For example, Mendiguren *et. al* [5] and Weiss *et. al* [6] tried to relate bending behaviour of dual phase steels and aluminium respectively to their springback. Hosseini *et. al* [2] developed a strain gauge-based technique to measure residual stresses of the order of yield stress in UHSS. In this work, the behaviour of a UHSS dual phase grade is investigated by comparing its bendability to its stretch performance and by characterising its through-thickness strain distribution during a bending test. The results show that the material can sustain significantly higher strain in bending compared to stretching.

2. Method
The chemical composition of the dual phase UHSS is given in Table 1.

Element	**C**	**Mn**	**Si**	**Nb**
Composition %	0.15	0.15	0.05	0.013

Table 1 Chemical composition of the dual phase grade

Stretch formability of the material was characterised with tensile tests and by measuring its forming limit curve (FLC). Tensile tests were carried out according to ISO 6892-1:2009 and FLC tests were carried out according to ISO 12004-2:2008. Tensile tests were conducted along, 45° and 90° to the grain direction. The tests were carried out on an Instron 250kN test machine, strains were measured with an optical/non-contact extensometer and loads were measured with a 100kN loadcell. FLC tests were carried on an Interlaken ServoPress 225 test machine. Strains were measured with a GOM digital image correlation (DIC) device mounted above the machine. Three repeats were carried out of each test.
Bending formability was characterised with plane strain bending tests that were carried out on a purpose built bending rig mounted on an Instron 5800 frame. To assess formability, a DIC device was used to capture strains along the thickness of the sheet (Fig.1).

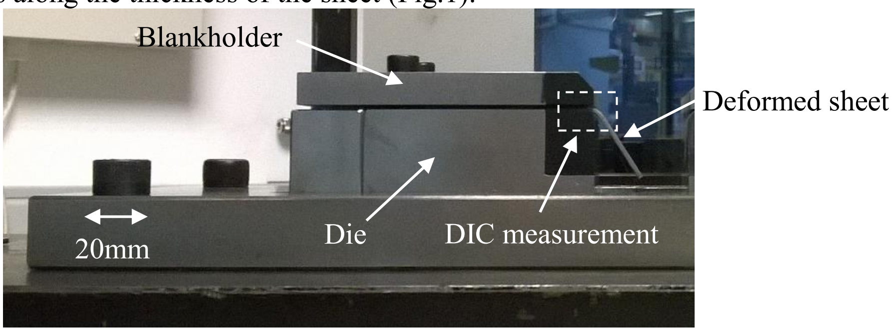


Fig.1 Photo of the bending rig mounted on an Instron 5800 frame

3. Results
The results of the tensile tests are in Table 2 and the results for the FLC tests are in Fig.2.

	0° to grain	45° to grain	90° to grain
0.2% proof stress MPa	700.4±9	715.4±6	737.4±9
Ultimate tensile strength (UTS) MPa	1046.7±0.5	1070.7±7	1080.6±12
r-value	0.38±0.02	0.49±0.03	0.46±0.03
n-value	0.14±0	0.14±0.01	0.14±0
Yield ratio = proof/UTS	0.67±0.02	0.67±0.02	0.68±0

Table 2 Summary of data for the dual phase steel used in this study

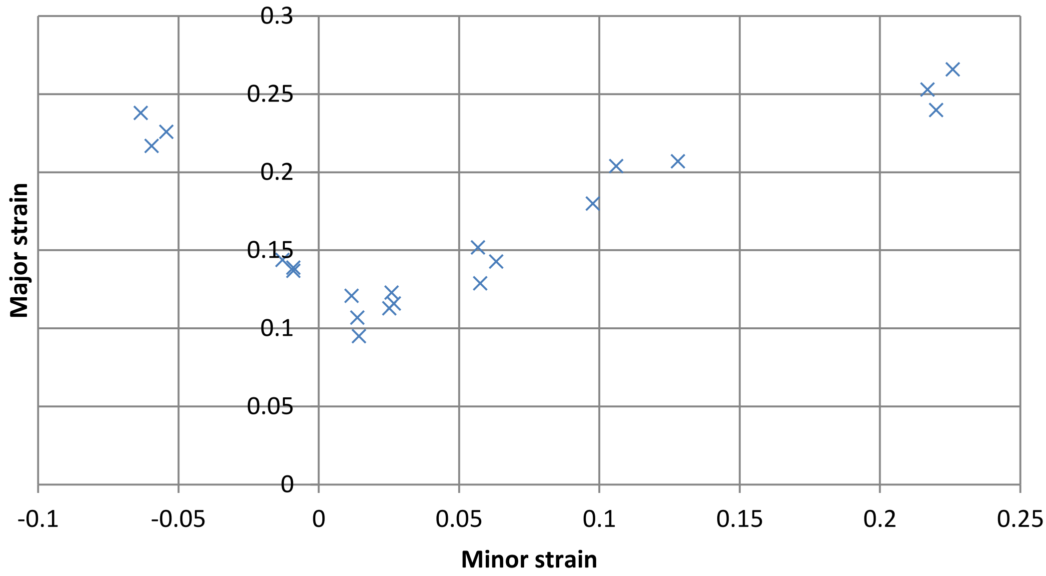
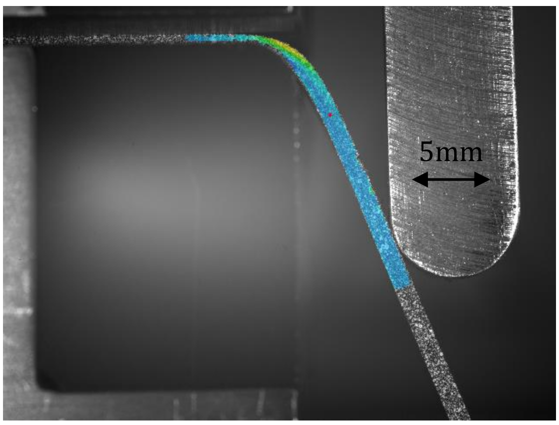


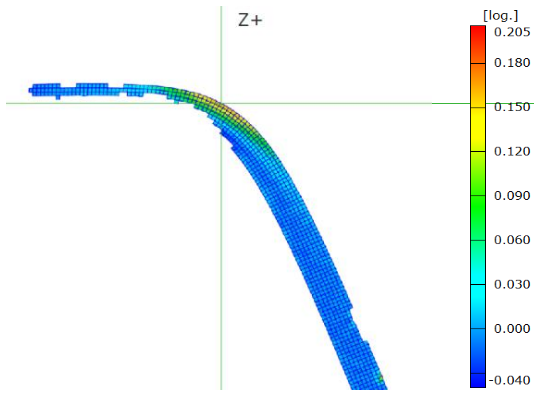
Fig.2 FLC curve for the dual phase steel

The results illustrate a material with a high strength to weight ratio (Table 1) but low formability, particularly in the plane strain region (Fig.2). Away from the plane strain path (Fig.2), formability increases so that in the biaxial region, failure takes place at around 0.25 strain. Its low formability is anticipated by a low work hardening rate of 0.14 (or high yield ratio of 0.67) in all directions with respect to its grain.

In plane strain bending, the material in the outer ligament of the bend was able to support greater strain than in the stretch mode experienced in the tensile and FLC tests (Fig.3). Compared to the plane strain deformation failure strain that was measured to be about 0.1-0.11 (Fig.2), the strain the bending sample supported was 0.16-0.17 (Fig.3). Unlike FLC samples, which necked and failed, analysis of the bending samples using scanning electron microscopy (SEM) did not reveal significant damage (Fig.4). With the current design of the bending apparatus, bending of the sample was limited to about 80°. As a result, it was not possible to explore the limits of bending formability of the material.



(a) Side view of the bending rig



(b) Contour plot – major strain

Fig.3 Major strain contour plot in plane strain bending (a) DIC image (b) Strain result

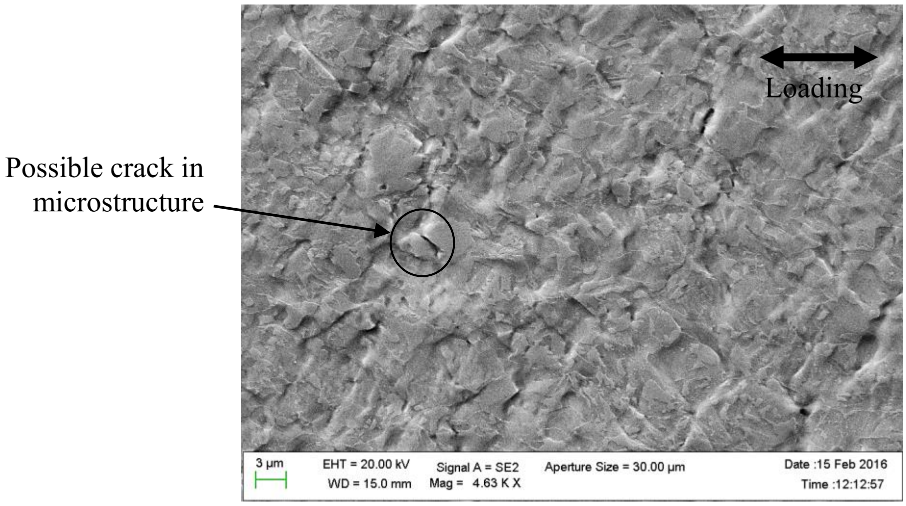


Fig.4 SEM micrograph of the highly strained region of the bending sample

4. Conclusions

Tensile tests and plane strain bending tests were carried out on a dual phase UHSS. The results showed that the material was able to support higher major strains in bending than in stretch. The full field major strain field showed that the high strain levels were found, as expected, in the outer ligament of the sample. However, despite the higher strains in bending, little evidence of damage was found in the microstructure of the material, suggesting that it is able to sustain even higher strains.

Acknowledgements

The authors would like to thank the Engineering and Physical Sciences Research Council for financially supporting this work and Tata Steel UK, Tata Steel BV for the supply of the materials. We had many useful discussions with the staff at Tata Steel UK and Tata Steel BV, The Hadley Group, Advanced Forming Research Centre, Jaguar Land Rover and data M Sheet Metal Solutions.

References

[1] Cable V, Parry-Jones R. Driving success – a strategy for growth and sustainability in the UK automotive sector. Automotive Council UK, 2013.

[2] Hosseini SB, Sagström E, Ottosson P, Troive L. A method for measuring residual stresses in rollformed hat profiles of ultra high-strength steel. In: Kolleck R, editor. IDDRG: TOOLS AND TECHNOLOGIES FOR THE PROCESSING OF ULTRA HIGH STRENGTH STEELS; Graz, Austria: Technical University Graz; 2010. p. 245-54.

[3] Kalpakjian S, Schmid SR. *Manufacturing processes for engineering materials*. 5th ed. Singapore ; London: Pearson/Prentice Hall; 2008. xxi, 1010 p. p.

[4] Lindgren M. Experimental and Computational Investigation of the Roll Forming Process: Luleå University of Technology; 2009.

[5] Mendiguren J, Hanselman S, Atzema E, Hodgson P, Rolfe B, Weiss M. Characterization of a Dual Phase Steel Using Tensile and Free Bending Tests. In: Yoon JW, Beynon J, Hodgson P, editors. NUMISHEET 2014; Melbourne, Australia: AIP Publishing; 2013. p. 659-62.

[6] Weiss M, Rolfe B, Hodgson PD, Yang C. Effect of residual stress on the bending of aluminium. Journal of Materials Processing Technology. 2012;212:877-83.